5   Coherent Phase Data Segment Layout in Data Storage Device~~Systems~~

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Field of the Invention

The present invention relates to the organization of data in data storage

15   devices~~systems~~, and more particularly, to the storage, retrieval and organization of

~~organization of~~ radially coherent data segments~~audio/video data stored~~ in disk drives

~~for uniform data retrieval rate~~.

Background of the Invention

20   Data storage devic~~systeme~~s such as disk drives provide ~~are utilized for~~ data

storage and retrieval in a variety of applications. A ~~typical~~ disk drive includes a spindle

motor for rotating a ~~data~~ disk, and ~~an actuator for moving~~ a transducer ~~head carrier that~~

~~supports read/write~~ heads that moves radially across the disk to read from and write

~~data to or read data from~~ concentric ~~data~~ tracks on the disk. Many disk drives include

25   multiple~~a plurality of~~ disks separated by spacer rings and stacked on a hub attached to

the spindle motor, and multiple transducer ~~a plurality of read/write heads, and a plurality~~

~~of head carriers, each head carrier supporting at least one read/write~~ heads that each

read from and write to a different disk surface.

30   The tracks are each divided into circumferential divisions that are arced along

the disk radius. The circumferential divisions each include a servo sector followed by a data sector. The servo sector contains servo information for positioning the transducer head over the track, and the data sector contains user data from an external device. The transducer head reads the servo sectors to position itself along the track as it reads

5   and writes to and from the data sectors. In addition, the servo sectors are embedded in the tracks along servo wedges that extend radially across multiple tracks.

To access a data segment ~~starting on a track~~, ~~in a seek operation~~ the transducer head ~~is~~ moves̲d̲ radially across the tracks to a̲the destination ~~desired~~ track where the

10   data segment starts during a seek operation. ̲Thereafter, the ~~rotation of the~~ disk rotates the ~~the~~ start of the data segment on the track under the transducer head for reading or writing to or ~~data to or reading data there~~from the data segment during a track following operation. The data segment can continue onto one or more other tracks, ~~wherein~~ in which case the transducer head ~~is~~ sequentially moves̲d̲ to the subsequent tracks for

15   accessing the remainder of the data segment.

~~-~~The response time ~~of the disk drive~~ for ~~in~~ accessing the̲a data segment includes ~~the sum of three~~ time periods for̲: (1) moving ~~the time period for the actuator to move~~ the transducer head to the destination̲~~desired~~ track (seek time), (2) rotating ~~the time~~

20   ~~period for~~ the start of the data segment ~~to rotate~~ under the transducer head (rotationa̲l̲ latency time ~~or rotational latency~~), and (3) ~~the time period for~~ recording or retrieving the ~~entire~~ data segment to or from the disk (transfer time). The access time is the ~~sum of the~~ seek time combined with ~~and~~ the rotational latency time~~is also known as access time~~. Furthermore, the response time is inversely proportional to the data transfer rate

25   (throughput). Thus, the access time is a significant performance feature since decreasing the access time decreases the response time which increases the data transfer rate of the disk drive.

~~A data rate, or throughput, in a disk drive with conventional data layout, is~~

30   ~~determined as the ratio of the transfer time for the data in a selected data segment and~~ ~~the response time for the data segment. For a randomly selected data segment, as in a~~

fragmented disk drive, the data rate for different data segments is random. FIG. 1 shows a conventional data segment layout in linear fashion. The illustrates conventional layout of Logical Block Addresses (LBA) in a disk drive disk space for maximizing forward sequential throughput. The layout is optimized for data disk drives

5   utilized for data storage in computer systems and maximizes forward sequential throughput. Each data segments (DS) are each stored in comprises two tracks (Tk) and contain a fixed number (x) of logical block addresses (LBA) per trackK shown in a linear fashion. For instance, data segment DS0 is stored in tracks Tk0 and Tk1 and contains LBA0 to LBA2x, data segment DS1 is stored in tracks Tk2 and Tk3 and

10 contains LBA2x+1 to LBA4x, and so on. The data segments have the same size, have the same number of LBAs, are arranged as sequential LBAs, occupy the same number of adjacent tracks, contain physically contiguous user data and fill the data sectors in the tracks they occupy.

15 The skew (phase advance or rotational skew angleadvancing phase) between adjacent (sequential) tracks TK as the disk rotates is selected as a rational combination of the number of sectors or LBAs per track, X. The skew has a The number X is used as a modulus with a factor chosen so that the rotational latency time that associated with the phase advance (skew), is just greater than the seek time between adjacent

20 tracks for the actuator to move the head from track to track, and just greater than the head switch time between different transducer heads. The head movement can be either across the surface of a disk or between heads to different disk surfaces.

However, the data segments are not radially coherent. For instance, data

25 segment DS1 has start and end rotational phases that are shifted relative to data segment DS0 by twice the skew, data segment DS2 has start and end rotational phases that are shifted relative to data segment DS1 by twice the skew and shifted relative to data segment DS0 by four times the skew, and so on.

30 Moreover, the intra-segment skew within a data segment is identical to the inter-segment skew between adjacent data segments. For instance, the intra-segment skew

of data segment DS0 between tracks Tk0 and Tk1 is identical to the inter-segment skew of data segments DS0 and DS1 between tracks Tk1 and Tk2, the intra-segment skew of data segment DS1 between tracks Tk2 and Tk3 is identical to the inter-segment skew of data segments DS1 and DS2 between tracks Tk3 and Tk4, and so on.

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Thus, the intra-segment skew between the start rotational phases of a data segment at adjacent tracks, and between the end rotational phases of a data segment at adjacent tracks, is the same as the inter-segment skew between the end rotational phase of a data segment and the start rotational phase of another data segment in

10 adjacent tracks. Likewise, the inter-segment skew between the data segments varies as a function of the radial distance between the data segments.

The conventional data segment layout provides random access times for randomly selected data segments, which maximizes the forward sequential data

15 transfer rate. As a result, the ~~Such~~ conventional data segment layouts usually provides good data transfer rates when the ~~result in~~ disk drive supports computer applications~~good performance for disk drives utilized in computer applications as measured by various well-known benchmark programs~~. However, the conventional data segment layout provides ~~a disadvantage of such layouts is the~~ poor data transfer

20 rates~~performance~~ when ~~of~~ the disk drive supports consumer electronics applications with ~~when used for storing a~~Audio-v ~~V~~ideo~~sual~~ (AV) data (such as movies)~~content~~. For instance, ~~example,~~ the access~~disk drive response~~ time when moving sequentially backward through the AV data~~content~~ (as for reverse play or reverse search) is significantly higher than when moving forward through the AV data~~content~~ since ~~. This~~

25 ~~is because as shown in FIG. 1,~~ the skew ~~starting and ending phase of any data segment DS, and accordingly its rotational phase relative to other data segments, is different according to its track. For a randomly selected data segment DS, the rotational phase or time to the next randomly selected data segment DS is a random variable. The phase difference (rotational phase)~~ between the data segments is

30 random and incoherent. ~~As such, when moving the head from one data segment to another data segment, especially when serving more than one AV stream, a wide range~~

of rotational phases and rotate times are encountered and the averages and maximum response times are adversely affected.

DFurther, in conventional disk drives typically perform, the seek operation time
5 and the rotational latency are treated separately, though access time is more important for any application than the individual time periods. The seek time and rotational latency are combined by default through a computer file system and a default access time results for a particular system and application. Therefore, the seek time and the rotational latency are not utilized in combination for efficient operation of the disk drive
10 in reducing access time. As such in many systems, a seek control system moves the head to a target track as fast as possible and then wait on average waits one-half a disk revolution for the start of the data-data segment to rotate under the transducer head to rotate under the head ("hurry up and wait"). Unfortunately, the seek time and the rotational latency time are treated separately and combined by default although the
15 access time is more important than the individual times. Furthermore, fFast movements of the transducer head to reduce the seek time result in unwanted acoustic noise, and lead to high power consumption.

DIn some disk drives have an attempted has been made to reduce the access
20 time overcome the above problems by alterengineering the file system. However, the file system disk drive designer has incomplete knowledge of the data segment physical layout of the data disk, and such knowledge can quickly become obsolete. As a result, the file system is disk drives are over designed and creates as described above, with resulting cost penalties.
25

Disk drives have also attempted to reduce the access time by Still other attempts have been made to overcome the rotational latency and seek time disconnect. One such attempt is seek-reordering the seek wherein the order of requests to the disk are reordered to minimize the access time over several such requests. AlThough
30 seek request reordering this method can be effective when the in disk drive supports s utilized in computer systems for computer applications, it is quite ineffective when the

disk drive ~~for~~ supports consumer electronics applications with ~~of~~ multiple data A̶V̶ streams of . ~~This is because the~~ isochronous ~~nature of~~ AV data since ~~streams makes order of requests for multiple AV streams important. As such,~~ changing the order of requests results in failure to record or retrieve the correct AV data at the correct time.

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There is, therefore, a need for ~~a system and method for~~ improving access times ~~the systematic reliability of response time and consequently the sustained throughput of disk drives. There is also a need for such a system and method to allow for improvement in managing~~ and reducing ~~seek~~ acoustic noise in disk drives that store AV

10   data.

Summary of the Invention

The present invention provides a data segment layout in a rotatable storage media and related storage and retrieval that satisfy this need.

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The storage media includes a first data segment stored in first tracks and a second data segment stored in second tracks. The first tracks include a first start track and a first end track, and the second tracks include a second start track and a second end track. The first data segment starts in the first start track at a start rotational phase,

20   ends in the first end track at an end rotational phase, starts in adjacent first tracks at start rotational phases offset by an intra-segment rotational skew angle and ends in adjacent first tracks at end rotational phases offset by the intra-segment rotational skew angles. The second data segment starts in the second start track at the start rotational phase, ends in the second end track at the end rotational phase, starts in adjacent

25   second tracks at start rotational phases offset by the intra-segment rotational skew angle and ends in adjacent second tracks at end rotational phases offset by the intra-segment rotational skew angle. Furthermore, the first and second data segments are radially coherent, and the start and end rotational phases are offset by an inter-segment rotational skew angle that is greater than the intra-segment rotational skew angle.

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In an embodiment, the first tracks are adjacent to one another, the second tracks

are adjacent to one another, the first end track is adjacent to the second start track, the first and second tracks have the same number of tracks, and the first and second data segments have the same size.

5   In another embodiment, the first data segment is physically contiguous user data that fills the user data storage areas in the first tracks, and the second data segment is physically contiguous user data that fills the user data storage areas in the second tracks.

10   In another embodiment, the first and second data segments are isochronous AV data. For instance, the first and second data segments are isochronous AV data from a single data stream, or alternatively, the first data segment is isochronous AV data from a first data stream and the second data segment is isochronous AV data from a second data stream.

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        In another embodiment, the inter-segment rotational skew angle is $360 - \alpha(N - 1)$ degrees where α is the intra-segment rotational skew angle, N is the number of first tracks and N is the number of second tracks.

20   In another embodiment, a rotational latency time for rotating the storage media across the intra-segment rotational skew angle is a first seek time for moving the transducer head between first adjacent tracks and between second adjacent tracks, and a rotational latency time for rotating the storage media across the inter-segment rotational skew angle is a second seek time for moving the transducer head between
25   the first end track and the second start track that is greater than the first seek time.

        In another embodiment, the storage device provides the same forward and reverse sequential access times for the first and second data segments.

30   In another embodiment, a method for performing a seek operation includes receiving a seek request to move a transducer head from a start track to a destination

track, determining a radial distance between the start and destination tracks, selecting a seek time as a function of the radial distance and whether the start and destination tracks are in a data segment or different data segments, selecting a command current as a function of the radial distance and the seek time, and moving the transducer head

5   from the start track to the destination track during the seek time in response to the command current.

In another embodiment, the seek time is selected from a first seek time for intra-segment seeks, a second seek time for inter-segment short seeks and a third seek time

10   for inter-segment long seeks, and the command current is selected to reduce acoustic noise.satisfies these needs. In one embodiment the present invention provides a method and data layout/pattern for organizing and allotting disk drive capacity in a data storage system including data storage media having at least one recording surface. A method for storing at least one set of data segments to said recording surface in

15   concentric data tracks includes the steps recording each data segment onto said recording surface such that each stored data segment has a start, an end and a rotational phase from that data segment to each of the respective ones of all other data segments, wherein the data segments are recorded with coherent relative rotational phases. The coherent phase layout provides substantially constant data transfer rate

20   to/from the storage media because the relative rotational phase or rotational time from one data segment to another data segment is deterministic.

In another embodiment, the first seek time is a rotational latency time for the

25   intra-segment rotational skew angle, the second seek time is a rotational latency time for the inter-segment rotational skew angle, and the third seek time covers a full stroke.

The relative rotational phases are predetermined, and each relative rotational phase can have one of a limited number of predetermined values. In one version, the

30   relative rotational phases from each data segment to respective ones of a first subset of the data segments in the set have one of said predetermined values, and the relative

rotational phase from that data segment to respective ones of a second subset of the data segments in the set have another of said predetermined values. Each data segment can include one or more tracks, and data tracks in that data segment can be offset by a predetermined skew angle. Alternatively, each track can include one more

5   data segments.

In one version, one or more incoming data streams are received and partitioned into data segments for storage in coherent phase. The data segments are recorded so as to obtain a nearly constant data storage transfer rate when reading the data from the

10   data storage media. The data segments read from the storage media are combined to reformulate one or more data streams from the data segments. In one embodiment of the present invention, the data storage system is a component of a computer system. In another embodiment, the data storage system can be a component of an audio video storage server. In that case, the data segments comprise audio visual data and the

15   method of the present invention is used to store and retrieve isochronous Audio-Video (AV) content for consumer electronics applications.

The present invention further provides a seek profile for disk drive including a transducer radially moveable relative to the tracks on a disk by an actuator controlled by

20   a servo circuit during a seek operation from a starting segment to a destination segment. Data is stored on the disk in segments with the coherent phase layout. Performing a seek operation from a starting segment to a destination segment includes obtaining a seek profile for controlled application of current to the actuator based on the seek profile, wherein the seek profile includes constraints for the seek operation as a

25   function of: (1) a seek distance representing the radial distance between the starting and destination segments, and (2) a seek time based at least on the relative rotational phase between the starting and destination segments. Current is then applied to the actuator as a function of said constraints to perform the seek operation. In one version, each seek operation is completed at the expiration of the respective seek time, and for

30   at least one set of seek distances, the respective seek times are predetermined. Further, the seek time between two data segments can be based on the relative

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~~rotational time between the data segments, wherein regardless of the seek distance between the two data segments, the seek operation need only be completed at the end of the respective seek time, not before. As such, in one version, wherein a set of data segments have the same inter-segment rotational time (or relative rotational phase), the seek time for each seek operation among two data segments in the set is the same, and preferably equal to said inter-segment rotational time. The actuator need only move the transducer as fast as needed to cover the seek distance by the end of the seek time, and not before. Therefore, for short seek distances in relation to long seek distances, the actuator moves the transducer at a lower velocity than for long seek distances, to cover the seek distance at the end of the seek time. This reduces seek acoustic noise.~~

In another embodiment, the data storage device is a disk drive and the storage media is a disk.

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Advantageously, t~~T~~he present invention provides a data segment layout that organizes and allocates storage capacity in a data storage device. The present invention improves ~~the systematic reliability of~~ response time and ~~consequently~~ provides a substantially constant ~~the~~ sustained data transfer rate to and from the storage media due to the deterministic rotational latency time between the data segments. The present invention also reduces ~~or throughput,~~ acoustic noise and is particularly useful for storing and retrieving ~~taking into account the electro-mechanical nature of a disk drive. At the same time the present invention preserves the random access nature of a disk drive, and the new benefits derived therefrom for the storage of~~ AV data ~~content~~from multiple data streams. ~~Additionally, the present invention allows for significant improvement in managing seek acoustic noise.~~

Brief Description of the Drawings

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings where:

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FIG. 1 shows a conventional data segment~~isk track~~ layout in linear fashion~~for a~~

~~disk drive~~;

FIG. 2 shows ~~an example~~ computer system <u>that includes</u> ~~including~~ a disk drive ~~with a data pattern layout according to one aspect of the present invention~~;

FIG. 3 <u>show</u>~~depicts~~ a top plan view of a ~~disk drive~~ head<u>-</u> ~~and~~ disk assembly

5 (HDA) and a block diagram of disk ~~drive~~ electronics <u>in</u>~~of~~ the disk drive ~~of FIG. 2 that implement and utilize principles of the present invention~~;

FIG. 4 shows a<u>n</u> ~~block diagram of the~~ architecture of ~~an embodiment of~~ the drive electronics ~~of the disk drive of FIG. 2~~;

FIG. 5 shows ~~an embodiment of~~ data <u>segment</u> ~~pattern~~ layout in ~~a~~ linear fashion

10 ~~for the disk drive according to the present invention~~;

FIG. 6A shows ~~an embodiment of~~ data <u>segment layout in angular fashion</u>~~pattern layout of FIG. 5 in concentric tracks according to the present invention~~;

FIG. 6B shows ~~an embodiment of~~ data <u>segment layouts in recording zones in angular fashion</u>~~pattern layout in different recording zones~~;

15 FIG. 7A shows a functional diagram of <u>a</u> ~~an aspect of the~~ servo controller <u>in the</u> drive electronics~~of FIG. 4 operating from seek and transducer motion information in seeking operations~~;

FIG. <u>8</u>~~7~~B shows a <u>n</u> ~~example~~ flow diagram <u>for</u> ~~of an embodiment of steps for~~ performing <u>a</u> seek operation~~s according to the present invention~~;

20 FIG. <u>9</u>~~8~~A shows ~~example~~ performance values for <u>the</u>~~a~~ disk drive~~according to the present invention~~;

FIG. <u>9</u>~~8~~B shows a <u>performance</u> plot ~~of performance indicia~~ for <u>the</u> ~~a~~ disk drive ~~according to the present invention~~;

FIG. <u>10</u>~~9~~ shows an ~~example block diagram of and~~ AV storage server <u>that</u>

25 <u>includes the disk drive</u>~~and AV system according to another aspect of the present invention~~;

FIG. 1<u>1</u>~~0~~ shows a flow diagram ~~of an embodiment of a process~~ for storing <u>AV</u> data in <u>the</u>~~a~~ disk drive ~~according to the present invention~~;

FIG. 1<u>2</u>~~1~~ shows a flow diagram ~~of an embodiment of a process~~ for retrieving <u>AV</u>

30 data <u>from</u>~~in~~ <u>the</u>~~a~~ disk drive ~~according to the present invention~~;

FIG. 1<u>3</u>~~2~~A shows ~~another embodiment of~~ a data <u>segment</u> ~~pattern~~ layout <u>in linear</u>

fashion ~~in a linear fashion~~in which ~~, according to the present invention, wherein~~ each data segment is one-half the track ~~in~~ size; and

FIG. 1~~3~~2B shows ~~another embodiment of~~ a data segment ~~pattern~~ layout in linear fashion ~~in a linear fashion, according to the present invention, wherein~~ in which each

5   data segment is one-third the track ~~in~~ size.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common throughout the figures.

10   **Detailed Description of the Invention**

FIG. 2 shows a ~~block diagram of an example~~ computer system 10 that ~~in which a method embodying aspects of the present invention can be implemented. The computer system 10~~ includes a central processing unit ("CPU") 1~~2~~4, a main memory 1~~4~~6, and a~~I/O~~ bus adapter 1~~6~~8~~, all~~ interconnected by ~~via~~ a system bus 18~~20~~. The

15   computer system 10 also includes ~~Coupled to the I/O bus adapter 18 is~~ an I/O bus 20~~2~~ ~~that can comprise e.g. a small computer system interconnect (e.g.,~~ SCSI, ATA ~~(IDE)~~, 1394, etc.) and ~~bus, and which supports~~ various peripheral devices such as 24 ~~including~~ an I/O device 22 and a ~~storage device/unit such as a~~ disk drive 2~~5~~4. The disk drive 2~~5~~4 includes drive electronics 26 and a head-disk assembly ~~28~~ ("HDA") 28. The

20   computer system 10 also includes ~~can further comprise~~ a network interface ~~device~~ 30 connected to the system bus 18~~20~~ for ~~data~~ communication ~~between the computer system 10 and~~ with other computer systems 32 via a network link 34 in a networked data processing system 36.

25   FIG. 3 shows ~~depicts~~ a top plan view of the HDA 28 and a block diagram of the drive electronics 26 ~~of the disk drive 25, incorporating principles and aspects of the present invention therein~~. The HDA 28 includes a rotatable magnetic storage disk 38, a DC brushless in-hub spindle motor (not ~~specifically~~ shown) that rotates the disk 38, a hub 40 containing and/or enclosing the spindle motor and spindle bearings, an ~~rotary~~

30   ~~voice coil~~ actuator assembly 42, a preamplifier 44 that includes a read signal amplifier, a write signal driver and a transducer head selector, a flex circuit 46 that connects the

drive electronics 26 to the HDA 28, ~~preamplifier/head select/write driver circuit 44~~ ~~connected to the rotary actuator by a flex circuit 46 enabling the HDA 28 to be~~ ~~connected to the disk drive electronics 26 mounted to the HDA 28 externally of the~~ ~~interior thereof,~~ and a base housing 50 to which the various components of the disk

5 drive 24 are mounted and aligned.

~~Typically, the~~ ~~storage~~ disk 38 is coated with a magnetic material that stores data in ~~the form of~~ longitudinal bipolar magnetic patterns written by digital saturation recording ~~techniques within each concentric data track~~. For simplicity, the following

10 discussion mentions only a single ~~storage~~ disk 3~~8~~5 in the disk drive 2~~4~~5. However, ~~as~~ ~~those skilled in the art will recognize from the following discussion,~~ the present invention is applicable to ~~is capable of use in~~ disk drives having multiple disks 38 mounted upon the ~~spindle~~ hub 40, with the number of disks 38 and associated ~~data~~ transducer heads affecting the vertical height of the disk drive.

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The actuator assembly 42 includes ~~conventionally comprises a~~ ~~transducer head~~ gimbal ~~assembly 52 for each disk data surface~~, a carriage ~~assembly 54,~~ and a rotary voice coil ~~actuator~~ motor (VCM) 56. T~~In the rotary-type actuator assembly 42,~~ the ~~transducer head~~ gimbal ~~assembly~~ 52 is attached to an outer end 58 of the carriage 54,

20 and ~~while~~ the VCM ~~actuator motor voice coil~~ 56 is attached to~~at~~ a hub end 60 of the carriage 54. A pivot 62 is c~~C~~entrally located along the carriage 54, and ~~is a pivot 62~~ ~~about which~~ the actuator assembly 42 rotates about the pivot 62 on a dual bearing assembly secured to the base housing 50. The pivot 62 is ~~located~~ adjacent to the ~~storage~~ disk 38 and ~~such that~~ the carriage 54 extends the ~~upper and lower transducer~~

25 ~~head~~ gimbal ~~assemblies~~ 52 over ~~the surfaces of~~ the ~~storage~~ disk 38. Consequently, selective activation of the ~~actuator voice coil motor~~ (VCM) 56~~,~~ rotates the actuator assembly 42 about the pivot 62 to ~~and~~ accurately positions a transducer head 64 supported by the gimbal ~~each transducer assembly~~ 52 over the ~~surface of the storage~~ disk 38.~~ As such, data can be written to, and can be read from, each data storage~~

30 ~~surface of the storage disk 38 by transducers within the transducer assembly 52.~~

Typically, the transducer ~~head 64~~assembly 52 includes ~~a dual head transducer assembly 64 including e.g.~~ a thin film inductive write element ~~head~~ and a shielded thin film magnetoresistive (MR) ~~thin film~~ read element ~~(not shown)~~. The ~~The dual head~~ transducer head ~~assembly~~ 64 is formed at an outer end of one rail of ~~e.g.~~ a two rail

5 aerodynamic slider 70 secured to the gimbal 52~~, as shown for example in FIG. 3~~. T~~In accordance with conventional practice,~~ the magnetoresistive ~~(MR)~~ read element is formed on the slider 70~~first, in order~~ to take advantage of the smoothness of the finished slider end surface, and then ~~. After the MR read element is formed,~~ the thin film~~ inductive write element is formed over the MR read element.

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A load beam ~~flexure assembly~~ 72 supports the ~~includes a~~ gimbal 52, the transducer head 64 and ~~secured to~~ the slider 70 at one end and is coupled to the carriage 54 at the opposite end~~and to a load beam~~. The load beam 72 provides a preloading gram force to the slider 70 to bias it towards the ~~facing~~disk 38~~s storage~~

15 ~~surface.~~ When the disk 38 is rotating, the slider 70 overcomes the spring bias of the load beam 72 and flies several microinches above the disk 38 on an air bearing and the transducer head 64 reads from and writes to tracks 74 in the disk 38 in accordance with Winchester technology. W~~The flexure assembly 72 connects at one end to the carriage; another end supports a slider 70 and the read/write elements over the disk~~

20 ~~surface.~~ When the ~~storage~~ disk 38 is not rotating, the slider 70 ~~and transducer assembly 64~~ rests upon a radially inward landing zone 76 of the disk 38~~surface. On the other hand, when the storage disk 38 is rotating, the slider 70 overcomes the load beam spring bias and "flies" several microinches above the disk surface on an "air bearing" in accordance with what is known in the art as Winchester technology.~~

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~~During flight, the actuator assembly 42 positions the transducers in the transducer assembly 64 over the multiplicity of concentric data tracks 74 and data segments DS defined on one, or the oppositely facing, storage surface of the storage disk 38 so as to read servo and user data and to write user data. However, when the~~

30 ~~disk drive 25 is deactivated, the sliders 70 are moved in unison by the carriage assembly 54 to the inner landing zone and "parked" such that they will not damage the~~

~~surface of the disk 38 by coming into contact with it.~~

The ~~disk drive~~ preamplifier/~~write driver circuit~~ 44 is connected _by,_ ~~via~~ a flex circuit 78, to the actuator assembly 42 so that electrical signals ~~may~~ reach the ~~head~~

5   transducer _head_ ~~assemblies~~ 64 via minute wires carried along the side of the carriage 54 and _the_ load beam _72_.

In the drive electronics 26, a microprocessor 80 implements a servo loop for positioning the actuator assembly 42 during seek and track following operations, a ~~The~~

10   ~~signals leaving and entering the HDA 28 via the flex cable 46 are utilized by a drive microcontroller 80 and other electronics including a~~ motors _driver_ ~~control driver ASIC~~ 82 _provides_ ~~which supplies~~ driv_ing_ signals to ~~operate~~ the spindle motor and the _VCM 56_ ~~rotary actuator~~, _and_ a ~~PRML~~ read/write channel _84_ ~~44 which receives and~~ decodes coded data from the disk _38 using partial response, maximum likelihood (PRML)_

15   _detection_ and _also encodes and_ ~~which encodes and~~ delivers coded data to the write driver ~~portion~~ of the _preamplifier_ ~~IC~~ 44.

A _controller_ ~~disk drive electronics ASIC 8~~6_4_ implements a SERDES/ENDEC function, ~~and~~ ECC function, a data sequencer, a memory controller, a bus level

20   interface_,_ and a microprocessor interface for interfacing the microprocessor 80 with other circuits. _A_ ~~including a~~ DRAM buffer 8_8_6 ~~which can~~ include_s_ microprocessor program instructions, seek profiles _and,_ data _segment_ ~~blocks~~ ~~being~~ transferred between the CPU _12_ ~~a host (not shown)~~ and the ~~data storage~~ disk 38~~, etc.~~. _For_ ~~The microprocessor 80 implements a servo loop for controlling positioning (following,~~

25   ~~seeking, etc.) of the rotary actuator 42. In one~~ example, the _DRAM buffer_ ~~memory~~ 8_8_6 includes program instructions for execution by the microprocessor 80 to implement the servo loop. _An internal data, address and control bus 90 connects the microprocessor 80, the motor driver 82, the read/write channel 84, the controller 86 and the DRAM buffer 88, and a drive interface bus 92 connects the controller 86 to the I/O bus 20._

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During _a seek_ ~~track settling and following~~ operations, the servo loop _receives_

receives actual position samples from the transducer head 64 based on position
information within the servo sectors that are read by the transducer head 64from
position information within embedded servo wedges via the read element, and
separately estimates the head position and ,velocity of the transducer head 64 and the

5   actuator bias force of the actuator assembly 42 and specifies in order to generate a
command current using a seek profile that causes and put out a control command value
via the motors drivcontroler ASIC 82 to drive control the VCM 56 to move head position.
During each seek operation from a starting track/segment to a destination
track/segment, the servo loop utilizes a seek profile in conjunction with head motion

10   information (e.g., position, velocity, etc.) to determine the control command value for
moving the transducer head 64s from the starting track/segment 74 to the destination
destination track 74/segment. During a track following operation, the servo loop
specifies the command current based on position samples provided by the transducer
head 64 in response to reading the servo sectors on the destination track 74, and the

15   command current causes the motor driver 82 to drive the VCM 56 to maintain the
transducer head 64 over the destination track 74. An internal data, address, control
bus structure 88 interconnects the microprocessor 80, motors control ASIC 82, PRML
read/write channel ASIC 44, disk drive electronics ASIC 84 and DRAM buffer chip 86.
A connection to the host computing equipment is provided by a drive interface bus 90.

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       Referring to FIG. 4 shows an architecture of in conjunction with FIG. 2, in
another embodiment, the drive electronics 26. The servo and data control functions of
the microprocessor 80, the motor driver 82, the controller 86 and the DRAM buffer 88
are depicted or organized as a data controller 94 and a servo controller 96,

25   respectively. The data controller 94 is connected to the I/O bus 20, and the read/write
channel 84 and the servo controller 96 are connected to the HDA 28. In addition, the
data controller 94 is connected to the servo controller 96 of FIG. 4 is shown to include
a data controller 92 by a bus 98 and to the read/write channel 84 by a bus 100, and
theinterconnected to a servo controller 94 via bus 96, and a read/write channel 84 is

30   connected to the read/write channel servo controller 9698 interconnected to the data
controller 92 via a data buffer bus by a bus 102100.

During a write operation, ~~Actual~~ positioning information ~~from data disks are induced into the transducers, converted from analog signals to digital data in the read/write channel 98, and transferred to the servo controller 94, wherein in a servo~~

5 ~~loop the servo controller 94 utilizes the head positioning information for performing seeking and tracking/following operations of transducers over the disk tracks 74. In one example, the servo controller can include the microprocessor 80 of FIG. 3, for executing program instruction to implement the servo loop.~~

10 ~~A typical data transfer initiated by~~ the CPU 124 sends a write request to the disk drive 24, the CPU 12 ~~to the disk drive 25 may involve for example a direct memory access ("DMA")~~ transfers user ~~of digital~~ data from the memory 146 onto the system bus 1820, the bus adapter 16 transfers the data from the system bus 18 to ~~(FIGS. 2 and 4).~~ ~~Data from the system bus 20 are transferred by the I/O adapter 18 onto~~ the I/O bus

15 202, and the data controller 94 partitions the incoming ~~. The~~ data ~~are read~~ from the I/O bus 202 into data segments (blocks) with appropriate header information ~~by the data controller 92, which formats the data into data blocks with the appropriate header information and transfers the data to the read/write channel 98. For example, the data controller 92 collects data into data blocks or segments~~ and appends eError dDetection

20 and cCorrection bits ~~to the blocks.~~ TThese ~~blocks are further collected into a service unit which is then passed to~~ the read/write channel 984 encodes the data segments and converts the data segments from digital to analog form suitable for the transducer head 64 to write to the disk 38. Concurrently, ~~a command is issued to~~ the servo controller 964 ~~to~~ causes the actuator assembly 42 to move the transducer head 64

25 ~~actuator assembly 64~~ to the appropriate tracks 74 during seek operations, and the transducer head 64 writes the data segments to the tracks 74 during track following operationscylinder. ~~One or more of said function can be implemented external to the disk drive as a software driver running in a host processor (e.g., CPU 14), such as for simple ATA disk drives. The read/write channel 98 operates to convert data between~~

30 ~~the digital form used by the data controller 92 and the analog form suitable for writing to data disks by transducers in the HDA 28.~~

During a read operation, the CPU 12 sends a read request to the disk drive 24. ~~For a typical request for transfer of data from the HDA 28 to the CPU 14,~~ the data controller 9~~4~~2 provides the servo controller 96 with the ~~a disk~~ tracks 74 in which the

5   data ~~/~~segments are stored, the servo controller 96 causes the actuator assembly 42 to move the transducer head 64 to the appropriate tracks 74 during seek operations, and the transducer head 64 reads the data segments from the tracks 74 during track following operations. The read/write channel 84 converts the data segments from analog to digital form and decodes the data segments, the data controller 94 removes

10   the header information and the appended bits and sends the data segments to the I/O bus 20, the bus adapter 16 transfers the data from the I/O bus 20 to the system bus 18 and the CPU 12 stores the data in the memory 14.~~location to the servo controller 94 where the requested data is stored. In a seek operation, the servo controller 94 provides control signals to the HDA 28 for commanding the actuator 42 to position the~~

15   ~~transducer assembly 64 and transducers therein over said disk track/segment for reading the requested data therefrom. The read/write channel 98 converts the analog data signals from the transducers into digital data and transfers the data to the data controller 92. The data controller 92 places the digital data on the I/O bus 22, wherein the I/O adapter 18 reads the data from the I/O bus 22 and transfers the data to the~~

20   ~~memory 16 via the system bus 20 for access by the CPU 14.~~

     ~~Referring~~ FIG. 5 shows a data segment layout in linear fashion according to the present invention. The data segments (DS) are each stored in two tracks (Tk) 74 and contain a fixed number (x) of LBAs per track 74. For instance, data segment DS0 is

25   stored in tracks Tk0 and Tk1 and contains LBA0 to LBA2x, data segment DS1 is stored in tracks Tk2 and Tk3 and contains LBA2x+1 to LBA4x, and so on. The data segments have the same size, have the same number of LBAs, are arranged as sequential LBAs, occupy the same number of adjacent tracks 74, contain physically contiguous user data and fill the data sectors in the tracks 74 they occupy, as is conventional.

30

     Moreover, the data segments are radially coherent. The data segments each

start at a start rotational phase (S) in a start track 74 and end at an end rotational phase (E) in an end track 74. For instance, data segment DS0 starts at start rotational phase S in track Tk0 and ends at end rotational phase E in track Tk1, data segment DS1 starts at start rotational phase S in track Tk2 and ends at end rotational phase E in

5   track Tk3, and so on.

The intra-segment skew (α) within a data segment is less than the inter-segment skew (R) between the data segments. For instance, the intra-segment skew of data segment DS0 between tracks Tk0 and Tk1 is less than the inter-segment skew of data

10   segments DS0 and DS1 between tracks Tk1 and Tk2, the intra-segment skew of data segment DS1 between tracks Tk2 and Tk3 is less than the inter-segment skew of data segments DS1 and DS2 between tracks Tk3 and Tk4, and so on.

The data segments each have a start rotational phase at, in one embodiment of

15   the present invention, each surface of a disk 38 carries a multiplicity of spaced apart concentric tracks 74. Each track 74 is divided into an equal number of circumferential divisions. These divisions are generally arced along the disk radius in accordance with an arc defined by the head and the rotary actuator. Each division begins with a servo sector or "wedge" and is followed by a user data sector. The head position servo

20   information is included in each servo wedge and the user data is recorded in each data sector. Because the servo information is included on the data surface, the servo sectors are said to be "embedded" in that they lie interspersed among the data sectors. Each servo wedge contains information used for accurate positioning of the transducers over each selected data track, so that user data may be written to, or read

25   from, an adjacent data sector.

As shown in FIG. 5, in one embodiment of the present invention data segments DS including user data are stored on the disk 38, wherein each data segment DS comprises one or more tracks 74. FIG. 5 shows an example track layout on the disk 38

30   in a linear fashion, wherein the data segments DS have coherent phase. As such, each data segment DS has a start "S", an end "E" and a relative rotational phase "R" relative

~~to other data segments DS. Each data segment DS has a predetermined rotational phase to another data segment DS. For each data segment DS, the rotational phase R from that data segment DS (e.g., end of the data segment) to each of the other data segments DS is predetermined, and can be selected from a limited range of values. As~~

5 ~~such, if a set of data segments includes ten data segments, each data segment DS has a distinct, but no necessarily different in value, predetermined rotational phase R relative to each of the other nine data segments in the same. In that example, two or more of the nine distinct relative rotational phases from said one data segment to the other nine data segments in the set can have the same predetermined value (e.g., FIG.~~

10 ~~5). Further, different subsets of the nine rotational phases can have different predetermined values (e.g., FIGS. 12A-B).~~

~~A phase difference between the start of a data segment DS and the start of another data segment DS is defined as a relative start phase (e.g., 0 in FIG. 5), and a~~

15 ~~phase difference between the end of a data segment and the end of another data segment is defined as a relative end phase (e.g., 0 in FIG. 5). In one layout version, the relative rotational phase of any data segment to any other data segment DS is independent of the start or end tracks of the data segments DS. Similarly, the relative start phase for any data segment DS is predetermined, and the relative end phase for~~

20 ~~any data segment DS is also predetermined, independent of the start or end tracks of the data segment DS.~~

~~In the example layout shown in FIG. 5, the start of each data segment DS is~~ defined ~~as~~ 0 degrees ~~,~~ and an ~~the~~ end rotational phase at ~~of each data segment DS is~~

25 ~~defined as~~ 360 ~~+~~+ α(N − 1) degrees where N is the number of tracks 74 within the data segment~~(N-1)xα, where N is the number of tracks 74 in a data segment DS and α is the skew angle between tracks within a Data segment DS.~~ For instance, data segment DS0 starts at 0 degrees in track Tk0 and ends at 360 + α degrees in track Tk1, data segment DS1 starts at 0 degrees in track Tk2 and ends at 360 + α degrees in track

30 TK3, and so on.

~~T~~-he inter-segment skew between the end ~~The~~-rotational phase ~~distance R from~~
~~the end~~ of a data segment and ~~DS to~~ the start rotational phase of any subsequent data
segment ~~DS~~, adjacent or otherwise, is ~~predetermined and the same (e.g., R=360~~ − α(N
− 1) degrees ~~(N-1)×α~~. For instance, the inter-segment skew between the end

5   rotational phase of data segment DS0 in track Tk1 and the start rotational phase of
data segment DS1 in track Tk2 is 360 − α degrees, the inter-segment skew between
the end rotational phase of data segment DS1 in track Tk3 and the start rotational
phase of data segment DS2 in track Tk4 is 360 − α degrees, and so on. -As a result,
~~such,~~ the inter-segment rotational latency time ~~period~~ from the end rotational phase of a

10   data segment ~~DS~~ to the start rotational phase of any subsequent data segment ~~DS~~
~~(inter-segment rotational time)~~ is predetermined and is the same.

The intra-segment skew ~~The skew angle α is selected to be greater than or~~
~~equal to track-to-track seek time (e.g.,~~ spans ~~between~~ about 20 to 30 percent of

15   ~~0.2×360 to about 0.3×360~~ degrees (72 to 108 degrees) ~~)~~. Furthermore, the intra-
segment ~~The~~ skew ~~angle α~~ can be adjusted to refine average and worst case access
response ~~times. In FIG. 5, for the data segment DS, the starts are the same and~~
~~constant (i.e., 0 degrees), the ends are the same and constant (i.e., 360+α degrees),~~
~~the relative start and end phases are the same and constant (i.e., 0 degrees), and the~~

20   ~~relative rotational phased R are the same and constant (i.e., 360-α degrees).~~

———Thus, the intra-segment skew between the start rotational phases of a
data segment at adjacent tracks 74, and between the end rotational phases of a data
segment at adjacent tracks 74, is the same for all data segments. The inter-segment

25   skew between the end rotational phase of a data segment and the start rotational
phase of another data segment is the same for all data segments. In addition, the inter-
segment skew is greater than the intra-segment skew and is 360 − α(N − 1) degrees
where α is the intra-segment skew and N is the number of tracks 74 that each data
segment occupies.

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The rotational phase R can be adjusted to allow skew angle between tracks for a given number of tracks per data segment DS to improve the average response time for a randomly selected data segment DS. Preferably, the skew between tracks within a data segment (e.g., the rotational angle between start of tracks, or the resulting track-to-

5   track seek time — track head switch time) is selected to be just greater than the maximum time for the actuator to move the head the distance of one track.

FIG. 6A shows the data segment layout another diagram of example track layout of FIG. 5 in angular fashion.

10

,and FIG. 6B shows data segment layouts in recording zones 104 in angular fashion. The disk 38 contains 16 concentric recording zones 104 that include an outer recording zone 104A and an inner recording zone 104B. A data segment layout an embodiment of data pattern layouts in different recording zones 91 is located in the

15   outer recording zone 104A, and another data segment layout is located in the inner recording zone 104B, described further below.

The data segments have the same start and end rotational phases and the same size in each recording zone 104, but the data segments have different start and end

20   rotational phases and different sizes in different recording zones 104. For instance, data segment DSi is stored in tracks Tkm and Tkm+1 and data segment DSj is stored in tracks Tkm+2 and Tkm+3 in the outer recording zone 104A, however data segments DSn and DSn+1 are stored in track Tkp and data segments DSn+2 and DSn+3 are stored in track Tkp+1 in the inner recording zone 104B. Thus, the outer recording zone

25   104A contains a data segment per two tracks 74, and the inner recording zone 104B contains two data segments per track 74.

The disk drive 24 uses variable frequency recording in which the sectors per track 74 varies by the recording zones 104. There are about twice as many sectors per

30   track 74 in the outer recording zone 104A than in the inner recording zone 104B. In addition, the data segments span more circumferential distance in the outer recording

zone 104A than in the inner recording zone 104B. In this manner, the data segment sizes vary linearly by the recording zones 104. ~~Referring to FIGS. 5 and 6A, data segment DS0 comprising tracks TK0, TK1; data segment DS1 comprising tracks TK2, TK3; data segments DS2 comprising tracks TK4, TK5; and data segment DS3~~

5   ~~comprising tracks TK6, TK7 are shown. Tracks TK0, TK2, TK4 and TK6 have the same start and end relative to each other. And, tracks TK1, TK3, TK5, and TK7 have the same start and end relative to each other. The skew angle between track pairs TK0, TK1 is shown as α. Similarly, the skew angle between track pairs TK2, TK3; TK4, TK5; and TK6, TK7, is shown as α. In this example, for each data segment DS the rotational~~

10   ~~phase R, or rotational time, to a subsequent data segment is always the same (i.e., 360-α).~~

       The servo controller 96 implements a servo loop using seek profiles that specify the command current in response to a seek request. The seek profiles specify the

15   command current as a function of the radial distance between the starting and destination tracks 74, the rotational latency time between the starting and destination tracks 74 and the relationship between the starting and destination tracks 74.

       The seek profiles specify a first seek time for seeks between adjacent tracks in a

20   data segment, a second seek time for seeks between data segments that are within a predetermined radial distance from one another, and a third seek time for seeks between data segments that are farther than the predetermined radial distance from one another. Furthermore, the first seek time is the rotational latency time for the intra-segment skew, the second seek time is the rotational latency time for the inter-segment

25   skew, and the third seek time is substantially greater than the rotational latency time for the inter-segment skew. Thus, the first seek time is for intra-segment track-to-track seeks, the second seek time is for inter-segment short seeks, and the third seek time is for inter-segment long seeks. The first seek time is sufficient for seeks between adjacent tracks, the second seek time is sufficient for seeks between tracks spaced by

30   less than the predetermined radial distance, and the third seek time is sufficient for seeks between the inner most tracks and outer most tracks (the full stroke) in the disk

38.

    The seek profiles specify the command current to perform the seek operation during the specified seek time rather than as fast as possible. The command current

5   for short seeks decreases and therefore the seek velocity, the acoustic noise and the power consumption decrease as the radial distance between the data segments decreases. Likewise, the command current for long seeks decreases and therefore the seek velocity, the acoustic noise and the power consumption decrease as the radial distance between the data segments decreases. In each instance, the seek operation

10   is completed at the expiration of the seek time, and preferably not sooner. As a result, the seek time, the command current and the seek velocity are constant between adjacent tracks within a data segment, the seek time is constant and the command current and the seek velocity are a function of the radial distance between data segments spaced by less than the predetermined radial distance, and the seek time is

15   constant and the command current and the seek velocity are a function of the radial distance between data segments spaced by more than the predetermined radial distance.

    Table 1 lists the seek times and radial distances for the disk drive 24. The first

20   seek time is 2 msec for intra-segment track-to-track seeks, the second seek time is 8 msec for inter-segment seeks between one and two thousand tracks, and the third seek time is 19 msec for inter-segment seeks between two thousand one tracks and the full stroke. For instance, the seek time for seeks within data segment DS0 from track Tk0 to track Tk1 is 2 msec, the seek time for seeks within data segment DS1 from track Tk2

25   to track Tk3 is 2 msec, and so on. Likewise, the seek time for seeks between data segments DS0 and DS1 from track Tk1 to track Tk2 is 8 msec, the seek time for seeks between data segments DS1 and DS2 from track Tk3 to track Tk4 is 8 msec, the seek time for seeks between data segments DS0 and DS2 from track Tk1 to track Tk4 is 8 msec, and so on. Furthermore, each recording zone 104 has two thousand tracks, and

30   therefore the seek time between data segments within a recording zone 104 is 8 ms.~~To provide a substantially constant data transfer rate, a seek profile for the servo system~~

can be designed according to seek time constraints such that the seek time between any two data segments in a set of data segments (e.g., data segments in a recording zone 91) is selected to be a predetermined value. For example, the seek time can comprise the maximum seek time that is necessary to seek from one data segment DS

5   to another data segment DS. As such, if for example 10 msec is required to seek from DS0 to DS1, then seeking from DS1 to DS4 also requires 10 msec. For short seeks (e.g., DS0 to DS1) compared to long seeks (e.g., DS0 to DS11), the servo system can take the entire 10 msec for the seek operation and move the head slower by inputting less power into the actuator (thereby reducing acoustic noise). Other

10   predetermined seek times can also be selected to achieve substantially constant data transfer rate to and from the disk.

When the seek performance requirement is so selected, the seek noise can accordingly be reduced significantly. This is a highly valuable attribute for hard disk

15   drives in A/V systems and A/V applications. For example, seek acoustic noise can be dramatically reduced by implementing a specification for the seek servo system (seek profile) according to Table 1 below. Additionally, the cost of seek servo amplifier and actuator motor can be reduced.

Table 1

Seek Distance	Seek Time
One track and head switches (intra-segment seeks) ~~(for intra-DS moves)~~	2 msec
One ~~Two~~ tracks to two thousand tracks (inter-segment seeks)	8 msec
Two thousand one tracks to full stroke (inter-segment seeks)	19 msec

~~Table 1. Example seek servo spec. for coherent data segment layout~~

5   Advantageously, the disk drive 24 provides a substantially constant data transfer rate. In addition, since the servo controller 96 takes the entire 8 msec for short seeks and the entire 19 msec for long seeks, aggressive time-optimal seek profiles are unnecessary, the seek performance is systematically relaxed and the command current is reduced, thereby reducing acoustic noise, power consumption and strain on the base

10   housing 50, the VCM 56 and the motor driver 82. Moreover, ~~In the context of Audio and/or Video data and streams, when the data is organized according to the present invention, the seek performance requirement is systematically relaxed.~~ Tthe average and worst case ~~r~~access ~~esponse~~ times are reduced, which is particularly beneficial when the disk drive 24 supports ~~improved. The reduction of the average and worst~~

15   ~~case response time is also a benefit of the present invention in cases where e.g.~~ a large number of simultaneous data streams and the AV data ~~are being serviced and/or the content~~ has become fragmented on the disk 38~~physically~~.

~~In one embodiment, as a result of a data segment layout according to the~~

20   ~~present invention, wherein the rotational phase R (and inter-segment rotational time) from a data segment DS to the start of any subsequent data segment DS is predetermined (e.g., the same, or selected from a limited number of predetermined values, etc.), seeks requiring less time than the inter-segment rotational time need not be completed any faster. As such, the seek time is selected based on the inter-~~

25   ~~segment rotational time, allowing a larger number of possible seek distances can be completed within an inter-segment rotational time.~~

An example servo loop implementing predetermined seek times according to the present invention is now described. Referring back to FIG. 4, for each seek operation to transfer data, the data controller 92 provides a destination track/segment DS (in relation to the current position of the head at a starting track/segment DS), to the servo controller 94 where data is to be transferred to/from a segment DS. The servo controller 94 provides control signals to the HDA 28 for commanding the actuator 42 to position the transducer over said destination track/segment DS for transferring data. For example, for a read operation, the read/write channel 98 converts the analog data signals from the transducers into digital data and transfers the data to the data controller 92. The data controller 92 places the digital data on the I/O bus 22, wherein the I/O adapter 18 (FIG. 2) reads the data from the I/O bus 22 and transfers the data to the memory 16 via the system bus 20 for access by the CPU 14.

In one version, the servo controller 94 implements a servo loop, and uses seek profiles for performing seek operations. For each seek operation from a starting track/segment DS to a destination track/segment DS, the servo controller 94 receives actual position samples from position information within embedded servo wedges via the read element in the head, then estimates head position and velocity, and uses a seek profile to generate and put out a control command value Icommand to the actuator VCM to move the transducers from the starting track/segment DS to the destination track/segment DS.

Destination segment DS position data on bus 96 provides coarse positioning information to the servo controller 94 for specifying a seek distance representing the radial distance that the actuator 42 must move the transducer from the starting segment DS (e.g., end of starting segment) to reach the destination segment DS (e.g., start of destination segment). The seek time comprises a predetermined time period for the transducer to cross over the tracks between the starting segment DS and the destination segment DS in the seek distance. The servo controller 94 uses seek information, including e.g. seek distance, on bus 96 and servo head position

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information on line 99 to generate a current value $I_{COMMAND}$ according to the seek profile, to control supply of input actuator current I_a to the VCM, resulting in controlled movement of the actuator assembly 64 such that the seek operation is completed by the end of the seek time, and preferably not sooner. As such, according to the seek

5 profile, the servo controller 94 generates the current command value Icommand such that each seek operation is completed at the expiration of the respective predetermined seek time.

For the example layout pattern of FIG. 5, the seek time is selected to be the

10 relative rotational time (inter-segment rotational time based on relative rotational phase R) between segments DS. Because in the pattern of FIG. 5 the relative rotational phase R for all the segments DS in the same, the seek time from each starting segment DS to any destination segment DS is the same, regardless of the seek distance in tracks between the starting and destination segments. Seeks requiring less time than

15 the inter-segment rotational time need not be completed any faster. Accordingly, if for example 20 msec is required to seek from DS0 to DS2, then seeking from DS1 to DS4 also requires 20 msec. For short seeks (e.g., DS0 to DS1) compared to long seeks (e.g., DS0 to DS11), according to an example seek profile the servo controller 94 uses the entire 20 msec for the seek operation and moves the head slower by inputting less

20 power into the actuator (thereby reducing acoustic noise). As such, according to the example seek profile, for short seeks the servo controller 94 commands less current input to the VCM to move the actuator, and for longer seeks, the servo controller commands more current input to the VCM to move the actuator faster. In either case, the seek distance is traversed by the transducer such the each seek operation is

25 completed by the end of the same seek time, and not sooner.

The seek profile can include constraints such as feed current values, target velocity per distance, expected distance to go, etc. for seek operations. In one version of the servo controller 94, for each seek operation, using the seek distance and the

30 predetermined seek time for the seek operation, the servo controller 94 obtains current level constraints from the seek profile, to generate the current command for the seek

operation. Then, during the seek operation, the servo controller 94 receives actual head position information, and compares the actual head position information with the expected head position information according to the seek profile, and adjusts the current command value to the actuator 42 as necessary to move the transducers

5   according to the seek profile, such that the seek is completed by the end of the seek time, not necessarily sooner.

For generating the current command, in one embodiment a feed current value FC is obtained or calculated by a microcontroller (e.g., microprocessor 80 in FIG. 3) in

10   the servo controller 94 to provide a base current value, depending upon the seek distance and seek time. The feed current value FC is an a priori prediction of current expected to be required to carry out the seek operation to achieve the seek performance described herein (e.g., Table 1) based on a data layout according to the present invention. It is based on information which quantify the operating

15   characteristics, some of which are developed during initialization calibration routines, and can be stored in memory. The feed current value FC allows more accurate adherence to a desired seek trajectory. The feed current value FC corresponds to the actuator current needed to keep the actuator on the idealized trajectory.

20   In this example, fundamentally, a nominal current waveform is preestablished for each seek distance to be traversed by the expiration of the respective predetermined seek time (preferably not sooner), wherein the seek time is based e.g. on the relative rotational phase R (or inter-segment rotation time) between the starting segment DS (e.g., end of starting segment) and the destination segment DS (e.g., start of

25   destination segment).

In versions where all segments DS in a set of segments have the same relative rotational phase R (e.g., FIG. 5), the seek time can be the same for all seek distances between all segments DS in that zone. In versions where the relative rotational phase

30   between a set of segments DS (e.g., segments in a recording zone 91) has one of several predetermined values (e.g., FIGS. 12A-B), the seek time can have one or more

predetermined time values based at least on the values of the relative rotational phases (e.g., seek time can be a linear function of inter-segment rotation time). The seek time can also be selected to be a maximum, minimum, or combination of said predetermined time values for all seek distances.

5

FIG. 7A shows an example functional block diagram of an embodiment of the servo controller 964. The servo controller 96 includes seek profiles 106 and a current regulator 108, and the seek profiles 106 include feed currents and expected motion (position and velocity) of the transducer head 64.

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During a seek operation, the actual motion (position and velocity) of the transducer head 64 is provided to the seek profiles 106 and the current regulator 108. In addition, the seek distance (the radial distance between the start and destination tracks 74) and the seek time (provided by Table 1) are provided to the seek profiles 106

15   and the current regulator 108.

The seek profiles 106 determine the feed current (FC) and the expected motion (EM) (position and velocity) of the transducer head 64 based on the seek distance and the seek time, and provide the feed current and the expected motion to the current

20   regulator 108. The feed current is a current profile that specifies a command current to perform the seek operation across the seek distance during the seek time (and not sooner). Thus, the feed current is a prior prediction of the command current expected to carry out the seek operation. The feed currents are determined by initialization calibration routines of the disk drive 24 and including the microcontroller 80 of FIG.3,

25   as configured by process steps according to the present invention to perform seek operations according to seek profiles 93, operating from seek and transducer motion information including e.g. actual head position, transducer velocity, transducer distance to destination segment DS, etc. in seeking operations. In this example the seek profile 93 includes e.g., a priori feed current values FC 93A, expected velocity/position

30   reference values 93B, etc. The a priori feed current values FC for the basic current corresponding to the seek distance and seek time can also be calculated by the

~~microcontroller 80 based on seek information which can reside in memory.~~

~~In one example, the feed current values FC (e.g., current profiles) are~~ stored in the DRAM buffer 88 in ~~memory as~~ a ~~FC~~ look-up table ~~of entries 93A, wherein each entry includes a current value FC,~~ indexed by the seek distance and the seek time, or alternatively, the feed currents are calculated by the microprocessor 80 based on the seek time and the seek distance. The expected motion includes velocity constraints on the transducer head 64.

~~–~~The current regulator 108 generates the command current ($I_{COMMAND}$) based on the feed current, the actual and expected motion (of the transducer head 64) and the seek distance and seek time, and the motor driver 82 drives the VCM 56 with an actuator current (I_A) based on the command current. The current regulator 108 uses the feed current as the command current as the transducer head 64 begins to move from the start track 74 towards the destination track 74. Thereafter, the current regulator 108 compares the actual and expected motion (of the transducer head 64) in conjunction with the seek time and seek distance and adjusts the feed current to generate the command current in accordance with the seek profile as the transducer head 64 continues to move towards the destination track 74. Thus, the current regulator 108 specifies the command current as the feed current based on a reference trajectory and then specifies the command current as the adjusted feed current based on the actual motion of the transducer head 64 to correct for deviations from the reference trajectory due to friction, torque constant variation, etc. ~~Each feed current profile comprises an a priori prediction of current expected to be required to carry out a seek operation (e.g., transducer traversing a seek distance) by the end of the respective seek time, not sooner. In one version of the servo controller 94, for each seek operation, using the seek distance and the predetermined seek time for the seek operation, the servo controller 94 obtains current level constraints from the seek profile, to generate the current command for the seek operation. Then, during the seek operation, the servo controller receives actual head position information, and in a regulation process 95 compares the actual head position information with expected~~

head position information 93B (EV) according to the seek profile, and adjusts the current command value in a regulate FC process 95 as necessary to move the head according to the seek profile, such that the seek is completed by the end of the seek time, not necessarily sooner.

5

In another version of the servo controller 94, for each seek operation, using the seek distance and the predetermined seek time for the seek operation, the servo controller 94 obtains current level from the seek profile 93, to generate the current command for the seek operation. Then, during the seek operation, the servo controller

10   receives actual head motion information, and compares the actual head motion information with the according to the seek profile, and adjusts the current command value as necessary to move the head according to the seek profile, such that the seek is completed by the end of the seek time, not necessarily sooner. For example, the expected values can include transducer motion constraints such as target velocity,

15   expected velocity, expected target velocity per distance, expected distance to destination segment DS, expected transducer position, etc. in a table 93B.

In one implementation, an actuator feed current profile FC in table 93A is predetermined and provides the amount of actuator current per distance from the

20   destination track. The predetermined look-up table 93B specifies the expected transducer velocity per distance from the destination track, EV, for each predetermined seek time. As such, in the regulation process 95, for each detected transducer location, a detected radial velocity is subtracted from the corresponding expected radial velocity. The difference is then used to adjust the profile current value for that detected

25   transducer location to provide the feed current values FC such that the seek distance is traversed by the end of the seek time.

———

FIG. 87B shows a n example flow diagram of an embodiment of steps performed

30   by the servo controller 94 for performing a seek operations. The disk drive 24 implements the seek operation by having the microprocessor controller 80 in the servo

controller 9~~6~~4 executes program instructions as including the current regulator 108 and send the command current to the motor driver 82ion process 95.

The microprocessor 80 obtains the seek distance between the start track 74 and

5 the destination track 74 by calculating the radial distance between the start track 74 (where the transducer head 64 currently resides) and the destination track 74 (specified by the seek request), and obtains the seek time from Table 1 based on the seek distance and whether the start and destination tracks 74 are intra-segment or inter-segment .For a seek operation, the microcontroller 80 obtains the distance between

10 the transducer location and the destination track/segment (seek distance), and obtains the seek time for the seek operation (step 1~~10~~4). The microprocessor 80 obtains the feed current from the seek profile in response to the seek distance and the seek time In one example, the predetermined seek time between each pair of segments DS (e.g., identified by unique number or location on reference disk) in a recording zone is stored

15 in memory. In another example, the predetermined seek time between each pair of segments DS is obtained based on the inter-segment rotational time between the two segments DS using the angular location of the end of the starting segment DS and the angular location of the start of the destination segment DS on the recording surface (i.e., relative rotational phase R). The microcontroller 80 then obtains a corresponding

20 FC value from the FC look-up table 93A using the seek distance and the respective predetermined seek time (step 1~~12~~03) and uses the feed current as the command current to move the transducer head 64 from the start track 74 towards the destination track 74 (step 114).

25 ⸻The microprocessor controller 80 obtains the actual position (current track 74) of the transducer head 64 used actual head position information, and subtracts the actual position (current track 74) current head position track from the destination segment track 74 to determine the radial distance (a total number of tracks 74) remaining to be crossed (step 1~~16~~05). At this initial stage, the transducer head 64 has

30 yet to reach the destination track 74 (step 118).

–The micro~~processor~~ ~~controller~~ 80 calculates the actual ~~radial~~ velocity of the transducer ~~head 64 by~~ ~~as~~ the number of tracks 74 ~~crossed over by~~ the transducer head 64 crosses ~~in~~ between ~~two~~ sampling intervals of the servo wedges (step 1209). ~~T,~~ ~~where a sampling interval is defined by a servo wedge passing under the transducer~~

5   ~~head. As such, during each sampling interval,~~ the microprocessor 80 detects the position of the transducer head 64 each sampling interval, and ~~location is detected, and~~ ~~the microcontroller 80~~ calculates the ~~radial~~ velocity of the transducer head 64 by determining ~~a difference in~~ the number of tracks 74 between~~: (1) a first transducer~~ ~~location detected during a~~ the current ~~present~~ sampling interval~~,~~ and the ~~(2) a second~~

10   ~~transducer location detected during a~~ preceding sampling interval. The velocity is ~~The~~ ~~microcontroller 80 determines the track difference between the two transducer locations~~ ~~to obtain the number of tracks crossed over by the transducer between the two~~ ~~sampling intervals, providing a measure of the actual radial velocity of the transducer.~~ ~~The radial velocity can be~~ expressed as tracks per ~~crossed over per sampling interval~~

15   ~~(e.g., tracks/sample).~~

The microprocessor 80 then compares the actual and estimated velocity of the transducer head 64, and the actual and estimated radial distance between the transducer head 64 and the destination track 74 (step 122) to determine correction

20   values (step 124) and applies the correction values to the feed current to adjust the command current so that the transducer head 64 more accurately follows the reference trajectory (step 126)~~and distance to go values are applied to address and compare to~~ ~~an expected trajectory value (e.g., velocity per distance remaining) stored in the~~ ~~trajectory profile look-up table (e.g. table 93B) in memory (e.g. DRAM 86) (step 111). A~~

25   ~~ratio value, Vr, of actual velocity value and the reference velocity value from said look-~~ ~~up table is calculated (step 113) in order to normalize the difference between the actual~~ ~~velocity and the reference velocity irrespective of magnitude thereof. The feed forward~~ ~~waveform value FC corresponds to the actuator current needed to keep the actuator~~ ~~assembly 64 on the idealized trajectory.~~

30
    ~~The normalized, signed velocity signal Vr is added to the feed forward value FC~~

~~to correct for any deviations from the reference trajectory due to friction, torque~~
~~constant variation, etc. (step 115).~~ The microprocessor 80 then repeats steps 116 to
126 un~~As such, the normalized error signal Vr is added to the priori feed forward value~~
~~FC which yields a corrected actuator current command value I~Command~. The process is~~
5 ~~repeated~till the destination track 74 ~/segment DS~ is reached (step 1~~180~~07). ~~Other~~
~~methods of implementing servo loops to perform the seek operations based on~~
~~predetermined seek times according to the present invention are possible, and~~
~~contemplated by the present invention. For instance, an example feed current~~
~~calculation based on expected velocity is described in the commonly assigned United~~
10 ~~States Patent No. 5,005,089, titled "High performance, high capacity micro-Winchester~~
~~disk drive", incorporated herein by reference, and can be modified to implement seek~~
~~operations according to the predetermined seek times described herein.~~

15 ~~According to the present invention, seek profile specification is given by required~~
~~seek time performance across the tracks on the disk, wherein in one example the seek~~
~~time is stepped (rather than conventional linear function) with a seek time for 1 track~~
~~seeks, another seek time for seek distances of 2 to x tracks, another seek time for~~
~~seek distances greater than x by less than y, etc. (e.g., Table 1). As such, excitation of~~
20 ~~the electromechanical system of the servo control can be relaxed, making the disk drive~~
~~quieter. Using a coherent phase data layout pattern according to the present invention.~~
~~A seek profile is selected to move the transducer from a starting segment to arrive at a~~
~~track where the destination segment starts, just before the start of the destination~~
~~segment rotates under the transducer, not sooner.~~

25

~~Preferably, the seek time is substantially equal to the inter-segment rotational~~
~~time between the end of the starting segment to the start of the destination segment.~~
~~For example using Table 1 above, to seek from a starting segment to a destination~~
~~segment, the servo controller 94 determines how far the destination data segment is in~~
30 ~~tracks (seek distance), and then if the seek distance is within e.g., 2 - 2000 tracks, the~~
~~transducer can take 8 msec to get to the destination segment (seek time = 8 msec). If~~

the seek distance is more than 2000 tracks, then the seek time is 19 msec. As such, according to one version of the present invention, transducer position information from the read/write channel, the physical layout of the data with coherent phase, and the servo loop using seek times based on inter-segment rotational time, are used together
5   to obtain nearly constant data transfer rate, and operate the disk drive quietly and with reduced power.

A data segment DS can be selected to be the amount of physically contiguous data (e.g., bytes, sectors, tracks, etc.) recorded or retrieved to or from the disk 38 each
10   time the actuator moves the heads 52 (e.g., in a skip-sequential manner). A data segment DS is distinguished from a File Allocation Unit (FAU) used in the context of file systems for computer applications (a data segment DS can include an FAU). The latter is usually contiguous but much smaller in size than a data segment DS. An FAU is typically between e.g. 4096 and 8192 bytes (8 to 16 sectors) while a data segment DS
15   is between e.g. 131 Kbytes (256 sectors) to more than 1 Mbytes (several thousand sectors or several tracks), or more. Preferably, the size of a data segment DS is selected by balancing among factors including: (1) preservation of the (forward sequential) throughput of the disk drive 25, (2) budgeting for error event management, (3) the size (and cost) of a DRAM cache buffer 86 in the disk drive 25, and (4) retaining
20   the random access nature of the disk drive 25. An example selection can be two or more tracks per data segment DS. Generally, though not necessarily, all data segments DS are of the same size. The data segments can be of different sizes, but with coherent phase.

25   In one version of the present invention, coherent phase can be forced on data segments DS with the choice of number of tracks per data segment size. The cache buffer size can also be adjusted to be larger than may otherwise be needed to take advantage of random access storage. In disk drives utilizing Variable Frequency Recording (VFR) (e.g., FIG. 6B), wherein track density varies radially, in recording
30   zones at the inner most tracks there are n sectors (blocks) per track and in recording zones at the outer most tracks there are about 2n sectors per track. Tracks in between
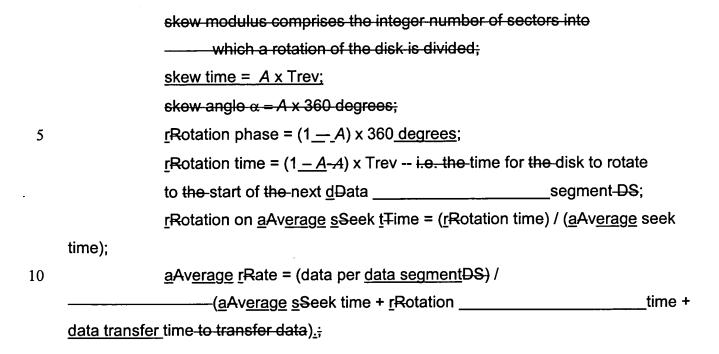
~~vary substantially piece-wise linearly. Preferably, the number of tracks per data segment DS is selected to vary linearly by radius. Therefore, a coherent phase data segment layout according to the present invention for seek time, and worst case response time or throughput performance, can be adjusted according to the possible~~

5 ~~seek distances and times for each VFR location on the disk 38.~~

~~Advantageously, a coherent phase data segment layout of the present invention provides the same forward and reverse sequential performance for data segment access. The substantially identical performance for forward and reverse sequential~~

10 ~~access is advantageous for AV 'trick-play' features, as for example fast-forward and fast-reverse searching through an AV content object. As such, the present invention affords more consistent response time, and thus data rates, particularly important for fast-reverse searching.~~

15 FIG. 98A shows <u>performance values</u> ~~the disk drive performance~~ for <u>the disk drive 24</u> ~~various e.g. intra-data segment track skew angle α selections for data segments DS,~~ <u>using the data segment layout of the present invention,</u> and ~~resulting inter-data segment rotational phase R (inter-segment rotational time).~~ FIG. 98B shows a performance <u>plot</u> <u>for the disk drive 24</u> ~~of the ratio of inter-segment rotational time on~~

20 ~~average seek time versus average data rate~~ <u>using the data segment layout</u> ~~according~~ <u>to</u>~~f~~ the present invention. <u>In these examples, the skew time is optimized as follows</u>~~This example shows how to optimize the skew time for performance, wherein:~~

  <u>skew modulus = integer number of sectors into which disk revolution is</u>
       <u>divided;</u>

25 <u>skew factor = integer number of sectors to set skew angle or time;</u>
  ~~skew time = A x Trev;~~
  Trev = time per <u>disk</u> revolution;
  A = (skew factor) / (skew modulus);
  <u>skew angle α = A x 360 degrees;</u>

30 ~~skew factor comprises the integer number of sectors that are~~
       ~~used to set the skew angle or time;~~

~~skew modulus comprises the integer number of sectors into which a rotation of the disk is divided;~~

skew time = A x Trev;

~~skew angle α = A x 360 degrees;~~

~~r~~Rotation phase = (1 _−_ A) x 360 degrees;

~~r~~Rotation time = (1 − A~~-A~~) x Trev -- ~~i.e. the~~ time for ~~the~~ disk to rotate to ~~the~~ start of ~~the~~ next ~~d~~Data segment ~~DS~~;

~~r~~Rotation on ~~a~~Average ~~s~~Seek ~~t~~Time = (~~r~~Rotation time) / (~~a~~Average seek time);

~~a~~Average ~~r~~Rate = (data per data segment~~DS~~) / (~~a~~Average ~~s~~Seek time + ~~r~~Rotation time + data transfer time ~~to transfer data~~)~~.~~;

The ~~s~~Skew modulus can be less than or equal to the number of servo samples per track 74 because ~~the~~ ~~a~~ disk drive 24 ~~system~~ cannot resolve time or phase below ~~th~~ ~~eat~~ servo sampling interval. Thus, ~~As such,~~ A is a rational number between 0 and 1. The skew modulus and the skew factor are selected for a desired rotational time. ~~T~~~~Preferable selections provide~~ he ~~an~~ inter-segment ~~r~~Rotational time to the next data segment is ~~DS of~~ about the ~~same as the~~ average seek time, and this establishes ~~for the actuator servo system. This can be used as~~ a guide for the ~~designing~~ data segment layout and the seek profiles ~~for disk drive systems with different parameters and geometry.~~

~~Because the present invention offsets many negative aspects of rotational latency, lower spindle speed disk drives are possible. As discussed herein, access time is the sum of seek time and rotate time, response time is the sum of access time and transfer time, and data rate is the ratio of the data transferred to the response time. As rotate time after seek arrival (rotational latency) is nearly zero due to a data segment layout according to the present invention, rotate time is effectively offset. Therefore, slowing the spindle speed (increasing Trev) has less impact on the data rate than for conventional data layouts. Thus, lower speed disk drives can be used to support a~~

~~given quality or number of A/V streams. Lower speed disk drives further reduce total acoustic noise.~~

~~The present invention improves the average performance of the disk drive 25 as~~
5 ~~measured by data rate, response time and access time. Further, the present invention significantly improves minimum data rates, maximum response time and maximum access time. These improvements afford more budget for error event management caused by environmental factors. External disturbances from shock or vibration can lead to excessive servo position errors or track miss-registration. This can lead to~~
10 ~~failure to read or write data on the first attempt. Read/write channel noise or spurious debris inside the HDA can also lead to such failure. These failures, when they occur, are referred to as error events and are usually managed by the disk drive in error management events such that data are faithfully reproduced. Error management consumes time for retry attempts and other remedies. Reducing the systematic time to~~
15 ~~service A/V streams/data increases the time for managing error events and thus improves total data reliability for a given A/V bandwidth requirement. Improving said budget improves the reliability of disk drives in consumer applications by making them more fit for such use.~~

20 ~~In addition, the present invention systematically reduces the need for aggressive time-optimal seek time performance using seek profiles described herein according to the present invention. By making this reduction, the seek servo system is redesigned to take advantage of the rotation time in a systematic manner. In so doing, additional improvements can be gained in seek acoustic noise reduction from the disk drive. Still~~
25 ~~further, demands on the disk drive system chassis design are reduced because seek reaction forces are reduced (chassis response to seek reaction forces can result in additional loss of response time performance.) This also makes the total acoustic noise generated by a disk drive less dependent on the system chassis and enclosure. And still further, the reduced performance required by the seek servo system allows the use~~
30 ~~of lower cost power amplifiers and motors.~~

Additionally, using the coherent phase layout the present invention provides symmetric forward and reverse sequential data segment DS access response time for 'trick-play' features. And, allows for reducing spindle spin speed with less loss in average and minimum data rates than compared to conventional layouts such in FIG. 1.

5 Lower spin speed will further reduce total disk drive acoustic noise and imbalance reaction forces transmitted through the system chassis that will still further reduce total acoustic noise. Lower spin speed also allows for a lower total cost disk drive.

In addition to use of the disk drive 25 in computer applications, a data segment

10 layout according to the present invention allows the use of the disk drive 25 for storing and retrieving AV content in e.g. an AV storage server. FIG. 109 shows an block diagram of an example AV storage server 1302 that includes the disk drive 24, according to the present invention. The AV storage server includes a controller 13204, data at least one buffers memory 134, a storage device 136 and a network interface

15 13806 and one or more storage devices 108 such as disk drives 25. The AV storage server 130 is connected to displays 140, and is also connected by a communication network 142 to component boxes 144 such as consumer electronics equipment in a networked AV system 146.

20 The AV storage server 130 receives multiple data streams that contain isochronous AV data from an external device, for instance a cable or the component box 144. The data streams are sequences of discrete fragments of AV data which are periodically transmitted in bursts that each contain about 0.5 to 1.0 seconds of AV data, and the data transmission is constant over time. The The disk drives 25 can store AV

25 information for various video titles such as movies. The controller 13204 controls the reading and writing of data to the disk drives 2 sends the multiple data streams to the disk drive 24 via the data buffer 134, which smoothes out the data streams, and the disk drive 24 partitions the data streams into corresponding data segments and stores the data segments on the disk 385. Thereafter, the controller 132 requests the multiple

30 data streams from the disk drive 24, which reads the data segments from the disk 38 and sends the data streams to the controller 132, and the controller 132 sends the data

streams to an external device, for instance the display 140 or the component box 144. ~~AV data read from one or more of the disk drives 25 can be output from the AV storage server for display on a display 110 connected to the AV storage server 102. Each disk drive 25 can simultaneously or sequentially provide AV information to one or more AV~~

5   ~~streams output from the AV storage server 102. Further, incoming AV data into the AV storage server 102 (e.g. from a cable or over a network) can be stored onto one or more of the disk drives 25. Each disk drive 25 can simultaneously or sequentially store AV information from one or more AV streams incoming into the AV storage server 102.~~

10   ~~The AV storage server 102 can be a component of an AV system 112 according to the present invention, wherein the AV system 112 comprises said AV storage 102 including an interface unit 114, a wired communication network 116 and component boxes 118 such as consumer electronics equipment. The AV system 112 can be a part of a home network system with connection to external cable or network for receiving AV~~

15   ~~information. One or more component boxes 118 can receive AV content from one or more disk drives 25 in the AV server. AV data is read from the disks 38 in the disk drives 25 to produce data streams which are transmitted to component boxes 118 or displays 110 for viewing. Further, one or more component boxes 118 can provide AV content to one or more disk drives 25 in the AV server 102. The data streams can~~

20   ~~comprise sequences of discrete fragments of data which are periodically transmitted in bursts so that over time a constant stream of data is transmitted. The data stream can be smoothed out using the buffer memory 106. In one example, each burst of video data can corresponds to about 0.5 to 1.0 second of video for a magnetic disk drive 25.~~Advantageously, the disk drive 24 provides the same forward sequential and reverse

25   sequential access times for reading the data segments since the data segments are radially coherent. This is particularly beneficial for trick-play features such as fast-forward and fast-reverse searching through the AV data.

FIG. 11 shows a flow diagram for storing AV data in the disk drive 24. The disk

30   drive 24 implements the write operation by having the microprocessor 80 in the data controller 94 and the servo controller 96 execute program instructions.

The microprocessor 80 ~~The present invention improves the systematic reliability of response time and consequently the sustained data rate or throughput, taking into account the electro-mechanical nature of the disk drives 25. At the same time the~~

5 ~~present invention preserves the random access nature of a disk drive, and the new benefits derived therefrom for the storage of AV content described above.~~

~~In another aspect the present invention provides a method for storing a stream of data to the data storage disk so as to obtain a nearly constant data storage transfer rate~~

10 ~~when reading the data from the data storage disk. FIGS. 10-11 show example flowcharts of processes for implementing an embodiment of the of present invention. To best understand the processes, the reader should also refer to FIGS. 2-4. In one implementation, the processes can take the form of computer programs typically executed by well-known data processing and control electronics including~~

15 ~~microprocessors or microcontrollers 80, 14 (e.g., PD787012 microcontroller manufactured by NEC). In one example, the computer programs can be executed by the microcontrollers 80 or 92 in response to data storage and retrieval commands from a processor 14. From the depicted flow charts, those skilled in the art can readily select an appropriate microcontroller and program the selected microcontroller to execute the~~

20 ~~disclosed processes.~~

~~Referring to FIG. 10, in one embodiment, the method of storing a data stream includes the steps of~~ partition~~sing~~ the incoming data stream into the data segments (step 15~~2~~0), ~~;~~ mov~~esing~~ the data segments into the DRAM a-buffer 8~~86 or 16~~ (step

25 15~~2~~2), ~~; for each data segment:~~ identify~~iesng~~ the~~one or more~~ data tracks 74 ~~on the data storage disk~~ to store the next ~~a~~ data segment (step 15~~2~~4), ~~;~~ direct~~sing~~ the VCM 56 to position the transducer head 64 over the identified tracks 74 (step 15~~2~~6)~~;~~ and record~~sing~~ th~~e~~at data segment in the identified tracks 74 with radially coherent phase relative to the other data segments stored on the disk 38 ~~according to the data segment~~

30 ~~pattern herein, wherein the start phase for each data segment is the same, and the end phase for each data segment is the same~~ (step 15~~2~~8). The microprocessor 80 repeats

steps 150 and 152 until the data stream is finished and repeats steps 154, 156 and 158 until the data segments are transferred from the DRAM buffer 88 to the disk 38.

5   The microprocessor 80 can execute steps 150 to 158, or alternatively, the CPU 12 can execute ~~In one example,~~ steps 1520 and 152, ~~122 can be executed by the processor 14,~~ and the microprocessor 80 can execute steps 1524, 1526 and 1528 ~~can be executed by the drive electronics 26 (e.g., microprocessor 80 or data controller 92). Other functional division of the computer program for execution by various processors and microcontrollers in the disk drive 25 and other system processors such as the CPU~~

10   ~~14 are also possible and contemplated by the present invention.~~ Furthermore, the AV data can be partitioned from a single data stream or multiple data streams into the data segments. Still further, steps 150 to 158 can be performed sequentially or simultaneously for multiple data streams. In every case, the disk drive 24 stores data segments that contain AV data in the data segment layout of the present invention,

15   regardless of whether the CPU 12 or the microprocessor 80 partitions the AV data into the data segments, regardless of whether the AV data is partitioned from one or more data streams, and regardless of whether the AV data from multiple data streams is processed simultaneously.

20   FIG. 12 shows a flow diagram for retrieving AV data from the disk drive 24. The disk drive 24 implements the read operation by having the microprocessor 80 in the data controller 94 and the servo controller 96 execute program instructions.

    The microprocessor 80 receives a request for the data segments (step 160),

25   identifies the tracks 74 that store the next data segment (step 162), directs the VCM 56 to position the transducer head 64 over the identified tracks 74 (step 164), retrieves the data segment in the identified tracks 74 and moves the data segment into the DRAM buffer 88 (step 166). The microprocessor 80 repeats steps 162, 164 and 166 until the data segments are read from the disk 38 and then reformulates the data stream by

30   combining the data segments (step 168).

The microprocessor 80 can execute steps 160 to 168, or alternatively, the microprocessor 80 can execute steps 160 to 166 and the CPU 12 can execute step 168. Furthermore, the AV data can be reformulated into a single data stream or multiple data streams. Still further, steps 160 to 168 can be performed sequentially or

5   simultaneously for multiple data streams. In every case, the disk drive 24 reads data segments that contain AV data in the data segment layout of the present invention, regardless of whether the CPU 12 or the microprocessor 80 reformulate the data stream, regardless of whether one or more data streams are reformulated from the data segments, and regardless of whether the AV data for multiple data streams is

10   processed simultaneously.

As such, in one scenario, a data stream is received by the disk drive 25 as bytes of data, and segmented into sectors. A set of sectors is grouped into a data segment by the disk drive electronics chip 84. The data segment is stored into a disk drive buffer 86, and the microprocessor 80 identifies the tracks on the data storage disk 38 to store

15   the data segment. The servo controller 94 positions the transducer 64 over the identified tracks, and the data segment is stored onto the tracks according to the coherent phase data segment pattern/layout herein.

In step 128, the data segments can be recorded such that the data tracks in

20   each data segment are offset by a predetermined skew angle α. Preferably, the skew angle is selected to minimize rotational latency as the transducer is positioned over adjacent tracks within a data segment to write data thereto and later read data therefrom, in a forward sequential fashion. Due to the coherent phase layout/pattern, the data segments are recorded so as to obtain a nearly constant data storage transfer

25   rate when transferring data to/from the storage media (e.g., data disk). In another embodiment of the present invention, the steps shown in FIG. 10 can be performed, sequentially or simultaneously, to store multiple data streams onto the data disk drive 25.

30   Referring to FIG. 11, the data segments can be read from the data disk 25 in response to data segment requests from a processor 14. Upon receiving a request for

a data segment stored on the disk 38 (step 130), the data tracks where the data segment is stored are identified (step 132); the VCM is directed to position the transducer over the identified tracks (step 134); and data is read from the identified tracks into a buffer 86 or 16 to be transmitted to the requester (step 136). The data

5   segments read from the disk can be combined to reformulate an output one or more data streams (step 138).

As such, in one scenario, the data segments can be read from the disk drive 25 in response to host command(s). The disk drive electronics chip 84 receives the

10 request for data segment. The microprocessor 80 identifies the location of the data tracks on the disk media where the data segment resides, and the servo controller 94 positions the transducer 64 over the identified tracks. The data is read, in form of a data segment, one sector at a time, from the tracks and stored into the disk drive buffer 86. When a certain amount of data has been stored in the buffer 86, the data is

15 reformulated and transmitted across the disk drive interface.

The steps in FIG. 11 can be performed, sequentially or simultaneously, to read data segments for multiple data streams from the disk, and reformulate the data streams for output. In one example, steps 130 and 138 can be executed by the

20 processor 14, and steps 132, 134 and 136 can be executed by the drive electronics 26 (e.g. microprocessor 80 or data controller 92). Other functional division of the computer program for execution by various processors and microcontrollers in the disk drive 25 and other system processors such as the CPU 14 are also possible and contemplated by the present invention. The processes described in relation to FIGS. 10-11 can also

25 be implemented in the system 102 of FIG. 9.

The data/track layout method of the present invention allows organizing and allocation of disk drive capacity when used to store and retrieve isochronous Audio-Video (AV) content for consumer electronics applications. The layout model can be

30 particularly useful when managing multiple AV streams over multiple content objects in a full and fragmented disk drive. The method is not dependent on any particular

interface, and can be implemented on e.g., ATA, SCSI, 1394, etc.. Using FCP-AV/C
with an on-board Stream Manager and Embedded File System can be used with the
method of the present invention e.g. for content objects used for delay broadcast
applications.

5

A coherent phase layout according to the present invention is laid out on the disk
38 such that data can be stored on the disk 38 according to that phase layout (e.g., the
segments have coherent relative rotational phase). Servo information provides track
location and angular position of data on the disk 38, allowing specification of an

10   address for every sector on the disk, wherein a collection of sectors makes up a
segment DS. Therefore, the servo information provides radial position and angular
position of each segment DS on the disk 38. The start of each track is recorded on the
disk 38 at fabrication, such that when data is later written in segments DS on the disk
38 by the servo system, the data is stored in segments having relative coherent phase.

15   As such, the coherent phase pattern is an attribute of the fabricated layout pattern on
the disk 38. In one example, the disk 38 of the disk drive 25 is initially formatted with S-
Scan using the coherent phase pattern layout described herein and shown by example
in the drawings. Thereafter, an LBA to physical transformation module in the disk drive
firmware maps data segments according to the coherent phase data segment pattern

20   herein.

According to the present invention, the rotational phase between the end of one
data segment to the start of another data segment, has a limited range of
predetermined possibilities or in a special case it is constant. The servo system in

25   implemented with information representing rotational time form end of one data
segment to start of another data segment. According to the present invention, a data
segment pattern with coherent phase is laid out on top of data layout, which is on top of
the servo format. In conventional data layouts, there is no linkage from the servo
system to the data layout, making it impossible to determine rotational time between

30   end of a piece of data to start of another piece of data.

5

10

~~In one example operation, a read/write command is issued and translated into a specific sector or sectors which start at a logical block address. The logical block address is converted (mapped) to a physical location on the disk surface using information including e.g. the size of each data segments, number of tracks per data segment, number of sectors per track, mapping of the defects, track skew angle, etc.. Firmware, or software that controls hardware, uses said information to convert logical block addresses to physical locations based on the coherent phase layout according to the present invention. The disk drive 25 then uses head(s) within the head transducer assembly 64 for writing and reading magnetic patterns on the rotating magnetic storage disk 38 in the physical locations in one or more concentric tracks. A coherent phase segment layout/pattern according to the present invention includes segments DS such that each segment DS has a predetermined rotational phase relative to another segment DS.~~

15

The disk drive 24 is initially formatted with the data segment layout using an S-scan during manufacturing. Thereafter, the microprocessor 80 maps the LBAs of the data segments into data sectors on the disk 38 using an LBA to physical location transformation module executed by firmware during write operations, and performs the inverse transformation during read operations.

20

FIG. 13A shows a data segment layout in linear fashion in which each data segment is one-half the track size. The tracks 74 each contain two data segments which each extend 180 degrees, similar to the data segments in the inner recording zone 104B. For instance, data segments DS6 and DS7 are stored in track Tk6, and so

25

on. The tracks 74 each contain 512 data sectors, and therefore the data segments each contain ~~For example, said relative rotational phase R for each data segment in FIG. 5 is the same (i.e., 360-α). The predetermined relative rotational phase R from a data segment to different data segments can be different and selected from a limited number of predetermined values. In the example LBAx and data segment DS layout described herein in relation to FIGS. 5-6, each data segment DS includes two tacks, and has the same relative rotational phase R (i.e., 360-α) to other data segments.~~

30

~~However, a data segment DS need not be larger than one track. This is particularly the case as linear densities for disk drives increase. Further, some applications are limited to less than one track.~~

5 ~~For example, when using ATA disk drives, there is a standard limit of~~ 256 data sectors, the standard limit of an ATA ~~per~~-command~~, which can be utilized as the size of a data segment DS~~. Furthermore, t~~-~~he data segments have two inter-segment skews relative to the other data segments, namely 180 degrees (one-half a revolution of the disk 38) and 360 degrees (a full revolution of the disk 38), and the intra-segment skew

10 is inapplicable. ~~Referring to FIG. 12A, as an example, each data segment DS can be selected to be ☐ track in length. In that case, there are two different predetermined relative rotational phases for each data segment DS . Predetermined rotational times (rotational phases R) from each data segment to another segment can be one of: (1) ☐ a full rotation time (R=180 degrees), or (2) a full rotation time (i.e., R=one revolution or~~

15 ~~360 degrees). The track-to-track seek time or skew angle is not applicable in this case, and the one track and head switch time are not necessary.~~

~~As such in the example data segment pattern shown in FIG. 12A, each data segment has a first relative rotational phase R relative to a first set of data segments,~~

20 ~~and a second relative rotational phase R relative to a second set of data segments. For example, the data segment DS0 has a first relative rotational phase R=360 degrees to a first set of data segments including data segments DS2, DS4, DS6, etc. And, the data segment DS0 has a second relative rotational phase R=180 degrees to a second set of data segments including DS1, DS3, DS5, DS7, etc.. Similarly, the data segment~~

25 ~~DS0 has a relative start phase of 180 degrees relative to data segments DS1, DS3, DS5, etc.. And, the data segment DS0 has a relative end phase of 180 degrees with relative to data segments DS1, DS3, DS5, etc.. Similarly, the data segment DS0 has a relative start phase of 0 degrees relative to data segments DS2, DS4, DS6, etc.. And, the data segment DS0 has a relative end phase of 0 degrees with relative to data~~

30 ~~segments DS2, DS4, DS6, etc..~~

Further, all tracks need not have the same number of segments DS because there can typically be several (e.g., 16) recording zones (e.g., FIG. 6B) that include different number of sectors per track. As such, the number of segments DS in each track can vary from zone to zone. For example, the number of different relative start,

5 end and rotational phases for data segments in each zone can increase from zones at the inner diameter to the zones at the outer diameter of the disk surface. The number and values of relative start, end and rotational phases for data segments in each zone can be selected as described by example herein to obtain one or more of the advantages of the layout format described herein.

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As such, each zone includes a set of data segments therein with coherent phase selected for that set. In FIG. 6B, two of a plurality of recording zones 91 are shown. The inner recording zone includes an example data pattern layout such as shown in FIG. 12A wherein each track 74 includes two data segments. The outer recording zone

15 includes an example pattern layout such as in FIG. 5 including data segments DSi and DSj where each data segment includes two tracks 74, and further shows start S and end E of each of the data segments DSi and DSj. Though in FIG. 6B, the layout patterns in the inner and the outer recording zones are different, in other versions the layout patterns in the recording zones can be the same wherein: in one case in all

20 recording zones 91 each data segment DS includes one or more tracks 74, in another case in all recording zones 91 each track 74 includes two of more data segments DS, etc.

FIG. 13~~2~~B shows ~~another embodiment of~~ a data segment layout ~~pattern layout~~ in

25 a linear fashion in which ~~, according to the present invention, wherein~~ each data segment is one-third the track ~~in~~ size. The tracks 74 each contain three data segments which each extend 120 degrees. For instance, ~~example, track TKn+2 comprises three~~ data segments DS56, DS57 and DS58 are stored in track Tkn+2, and so on~~(track and DS numbers are randomly selected for purposes of example only)~~.

30

The data segment layouts in FIGS. 5, 13A and 13B can be stored in different

recording zones 104 on the disk 38. In one version, in a disk with multiple recording zones (e.g., FIG. 6B), a first zone on a recording surface of the disk can include the pattern layout of FIG. 12A and a second zone on that recording surface can include the pattern layout of FIG. 12B.   Yet in another version, where the disk includes multiple

5   recording zones, and each data segment DS includes one or more tracks (e.g., FIG. 5), the number of tracks per data segment can be different in different recording zones. Further, the present invention contemplates a recording surface with different recording zones, wherein in at least one recording zone each data segment includes one or more tracks (e.g., FIGS. 12A-B), and in at least another recording zone each track includes

10   two or more data segments (e.g., FIG. 5).

For pattern layouts such as shown by example in FIGS. 12A-B, where the relative rotational phase between segments has one of several predetermined values, the seek time for seek operations between segments in each recording zone can have

15   one or more predetermined time values based at least on the values of the relative rotational phases (e.g., seek time can be a linear function of inter-segment rotation time). The seek time can also be selected to be a maximum, minimum, or combination of said predetermined time values for all seek distances.   For example, for the pattern of FIG. 12A, the seek time can comprise the predetermined rotational times from each

20   starting data segment to a destination data segment, including: (1) time for ☐ a full disk rotation time (R=180 degrees), or (2) time a full disk rotation time (i.e., R=one revolution or 360 degrees).

The seek time for each seek operation between two segments in FIG. 12A is

25   obtained based on the rotational time from the track where the starting data segment ends to the track where the destination data segment starts. In one example, the predetermined seek time between each pair of segments (e.g., identified by unique number or location on reference disk) is stored in memory to access and use by the servo loop.   For example the servo controller 94 can access a seek time table (stored in

30   memory 86, or within the servo controller 94, or on the disk, etc.) for each recording zone, wherein each seek time table includes information representing the

~~predetermined seek time for each pair of data segments in that recording zone. In~~
~~another example, the predetermined seek time between each pair of segments is~~
~~obtained from the inter-segment rotational time between the two segments based on~~
~~e.g. the angular location of the end of the starting segment and the angular location of~~

5   ~~the start of the destination segment on the recording surface of the disk.~~

─────The~~ough in the embodiments described herein a~~ disk drive 24 is ~~is used~~
~~as~~ an example ~~of a data storage system or~~ data storage device, however ~~other~~
~~examples are possible. For example,~~ the present invention is applicable to ~~can be~~

10   ~~implemented in~~ other data storage devices with rotatable storage media such ~~as e.g.~~
CD players, and DVD players, ~~CD-ROM, etc~~.

The disk drive 24 can include an on-board stream manager and an embedded
file system with FCP-AV/C for delay broadcast applications.

15

The data segment can be physically contiguous user data (bytes, sectors, tracks,
etc.) recorded to and retrieved from the disk 38 each time the actuator assembly 42

20   moves the transducer head 64 in a skip-sequential manner. For instance, the data
segment can be bytes of user data segmented into data sectors. The data segment is
distinguished from a file allocation unit (FAU) used in file systems for computer
applications. A FAU is typically 4096 to 8192 bytes (8 to 16 data sectors) while a data
segment is typically 131 Kbytes (256 data sectors) to more than 1 Mbyte (several

25   thousand data sectors or several tracks 74). Furthermore, a data segment can include
a FAU.

The data segment size can be selected by balancing (1) preserving the forward
sequential data transfer rate, (2) budgeting for error event management, (3) reducing

30   the size and cost of the DRAM buffer 88, and (4) retaining the random access nature of
the disk drive 24. The data segment need not be larger than one track 74, particularly

as linear bit densities on the tracks 74 increase, or for applications that limit the data segment size to less than one track 74. Furthermore, the data segments can have the same or different sizes as long as they are radially coherent.

5   The data segment layouts illustrated in the drawings omit the servo wedges for convenience of explanation, however the present invention can be and preferably is implemented in rotatable storage media with embedded servo patterns.

         The seek time can have one or more predetermined time values based on the

10   rotational latency times of the intra-segment and inter-segment skews. The seek time can also be a maximum, minimum, or combination of the predetermined time values for all seek distances. Furthermore, the first seek time can be substantially equal to the rotational latency time for the intra-segment skew, the second seek time can be substantially equal to the rotational latency time for the inter-segment skew, and the

15   third seek time can be substantially greater than the rotational latency time for the inter-segment skew.

         The intra-segment and inter-segment skews are measured in a single rotational direction as the transducer head 64 passes circumferentially over the disk 38 due to the

20   rotation of the disk 38. Furthermore, the intra-segment and inter-segment skews are referenced between the tracks 74 in a single radial direction. For instance, the intra-segment skew between tracks Tk0 and Tk1 is measured from the end rotational phase of track Tk0 in a single rotational direction (as the transducer head 64 passes circumferentially over the disk 38 from left to right) and is referenced between tracks

25   Tk0 and Tk1 in a single radial direction (as the transducer head 64 moves radially across the disk 38 from track Tk0 to track Tk1 from top to bottom). Likewise, the inter-segment skew between tracks Tk1 and Tk2 is measured from the end rotational phase of track Tk1 in a single rotational direction (as the transducer head 64 passes circumferentially over the disk 38 from left to right) and is referenced between tracks

30   Tk1 and Tk2 in a single radial direction (as the transducer head 64 moves radially across the disk 38 from track Tk1 to track Tk2 from top to bottom).

The microprocessor 80 can be a PD787012 microcontroller by NEC.

5   The present invention is applicable to other servo loops that perform seek operations based on predetermined seek times. See, for instance, U.S. Patent No. 5,005,089 which is incorporated by reference.

The present invention has been described in considerable detail with reference to certain preferred versions thereof,; however, other versions are possible. Therefore,
10   the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

Abstract

A—— rotatable storage media includes a first data segment stored in first tracks and a second data segment stored in second tracks. The first tracks include a first start track and a first end track, and the second tracks include a second start track and a second end track. The first data segment starts in the first start track at a start rotational phase, ends in the first end track at an end rotational phase, starts in adjacent first tracks at start rotational phases offset by an intra-segment rotational skew angle and ends in adjacent first tracks at end rotational phases offset by the intra-segment rotational skew angles. The second data segment starts in the second start track at the start rotational phase, ends in the second end track at the end rotational phase, starts in adjacent second tracks at start rotational phases offset by the intra-segment rotational skew angle and ends in adjacent second tracks at end rotational phases offset by the intra-segment rotational skew angle. Furthermore, the first and second data segments are radially coherent, and the start and end rotational phases are offset by an inter-segment rotational skew angle that is greater than the intra-segment rotational skew angle. A method for storing at least one set of data segments in a data storage system including data storage media having at least one rotatable recording surface, where the data segments are stored in concentric data tracks, each recorded data segment including a start, an end and a rotational phase from that data segment to each of the respective ones of all other data segments in the set, wherein the data segments are recorded with coherent relative rotational phases. For each data segment in the set the relative rotational phases of that data segment to respective ones of all other data segments in the set are predetermined. Further, the rotational phases from a data segment to respective ones of all other data segments in the set comprise the rotational phases from the end of that data segment to the start of the respective ones of all other data segments in the set, and have one of a limited number of predetermined values. The data segments are recorded so as to obtain a nearly constant data storage transfer rate when reading the data from the data storage media. The data segments read from the storage media can be combined to reformulate one or more data streams from the data segments. The data storage system can be a component of a computer system. The data storage system can be also be a

~~component of an audio video storage server. In that case, the data segments comprise audio visual data and the method of the present invention is used to store and retrieve isochronous Audio-Video (AV) content for consumer electronics applications.~~